An Ecoregion-based Conservation Assessment and Conservation Opportunity Area Inventory for the Lower Midwestern USA

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ABSTRACT:
We calculated landscape metrics from the National Land Cover Database (NLCD) and digital elevation models (DEMs) in order to create a conservation opportunity area (OA) coverage and rank ecoregions of Iowa, Kansas, Missouri, and Nebraska in terms of environmental quality. Ecoregions of northern Iowa and those that border the Missouri River in Nebraska and Missouri scored low for environmental quality, whereas subsections in the Ozark Highlands, Black Hills, Northwestern Great Plains, and Nebraska Sand Hills scored high. Conservation opportunity areas were defined as natural and semi-natural land cover patches that are away from roads and away from patch edges, and were modeled by creating distance grids using the NLCD and the Census Bureau's TIGER roads files. Conservation opportunity areas comprise 30.4% of the study area under a liberal model that counted patches closer to roads and patch edges, and 5.0% under a more conservative definition. Finally, we modeled landforms via neighborhood analysis of DEMs, and used landform representation as a conservation target to show how the OA coverage can be combined with other data to facilitate conservation planning in the St. Francois Knobs & Basins of southeastern Missouri. The ranking of ecoregions and delineation of OAs should be viewed as significant steps forward in the iterative process of developing more detailed conservation plans that incorporate additional data on conservation targets and evaluate design issues such as reserve size and position.

Index terms: conservation assessment; conservation opportunity areas; Midwest environmental assessment; natural resource planning; ecoregion planning

INTRODUCTION

Many geographic information system (GIS)-assisted, state- or ecoregion-based conservation assessments have been completed over the past five years (Anderson 2000, Capen et al. 1999, Defenders of Wildlife 1998, Hoctor et al. 2000, Jennings 2000, Jones et al. 1997, Kautz and Cox 2001, Noss et al. 1999, Ricketts et al. 1999, Riley et al. 1999). Some efforts have focused on ranking polygons (e.g. watersheds, EPA E-MAP hexagons, road-bounded blocks) by attaching variables to each polygon, whereas others have overlain results from a variety of independent fine- and coarse-scale analyses to produce a summary result.Conservation targets have centered on a variety of topics, including total vertebrate diversity (Jennings 2000), rare species and communities (Groves et al. 2000), enduring features (Capen et al. 1999, Kavanagh and Iacobelli 1995), or combinations of these and other variables (Hoctor et al. 2000). In the lower Midwest, a variety of local, state, and national organizations with diverse responsibilities, goals, and conservation targets are working toward conservation planning. No single, definitive outcome that identifies and ranks conservation priority areas will be accepted by all of these groups. Therefore, one primary focus is to provide relevant data to a variety of workers who will in turn complete their own conservation plans. Our goals were to (1) assess environmental quality of all ecological subsections that intersect the four Midwestern states of Iowa, Kansas, Missouri, and Nebraska (Figure 1), (2) provide a finer-resolution data layer that shows the location and extent of conservation opportunity areas (OAs) within the region, and (3) provide an example of how the OA data layer can be used in conjunction with data relevant to one conservation target, landform representation, to facilitate conservation planning.

METHODS

We used Geographic Information System (GIS) techniques to integrate and aid in the interpretation of existing data and to create new data layers. All data were gathered and re-projected as needed into Albers Equal Area projection to facilitate accurate measurement of area across the region.

Base Data Creation

Land Cover Metrics

We used the NLCD, derived from 30-meter resolution classified Landsat 7 Thematic Mapper satellite data, to calculate land cover metrics (Vogelmann et al. 2001). We reclassified the NLCD from 21 land cover classes for the study area to seven major classes: forest, shrubland, grassland, cropland, urban, barren or sparsely vegetated, and water. We calculated a suite of commonly used land cover metrics by ecological subsection (Frohn 1998, Jones et al. 1997, McGarigal et al. 1995). Following the work of Jones et al. (1997) and Wickham et al. (1999), we combined land cover metrics with other variables, including digital elevation models (DEMs) and streams data, to form additional indices. For a complete summary of calculated metrics and results by ecological subsection see Diamond et al. (2001). We included three land cover-derived metrics in the calculation of an overall environmental quality index for each subsection (defined below), including anthropogenic vegetation along streams, a human use index, and cropland on more than 5% slope. Anthropogenic vegetation along streams was calculated as the sum percentage of urban, cropland, and barren or sparsely vegetated land cover within one 30-meter pixel along stream corridors from the 1:100,000 scale National Hydrography Dataset. The human use index was calculated as the sum percentage of cropland, urban, and barren or sparsely vegetated land. Slope is one of the most important factors in determining runoff, erosion, and pollution potential from cropland, but potential runoff and erosion vary across soils due to other factors as well (Renard et al. 1997). Thus, soil variation will not allow selection of a definitive threshold for slope at which erosion always becomes dramatically more pronounced. We selected cropland on 5% slope as a conservative metric; Jones et al (1997) used a 3% threshold, which they selected based on a classification of soil slope classes (Wischmeier and Smith 1978).

Creation of Distance Grids for Land Cover Patches and Roads

Each 30-m pixel in a grid was assigned a value from zero to nine for distance into the interior of a forest, grassland, shrubland, or 'mosaic' land cover patch, and distance away from a road. Many studies have shown that the impacts of edge and habitat fragmentation vary among species and land cover types (see Noss and Csuti 1997, Villard et al. 1999). Likewise, the impacts of roads, and of different road types, vary by species and habitat (see Trombulak and Frissell 2000). Therefore, we selected a mathematical rule for assigning cell values to create the distance grids for land cover and roads. The interval between high and low values for each category, is 1.5 times the distance between high and low for the category below it. A cell value of one corresponds with all cells zero to 30 meters from the edge of a land cover patch or a road right-of-way, and a two is assigned to cells 30 to 75 meters from the edge, and so on. Interstate highways with limited access (see TIGER roads data files at http:/www.census.gov/geo.maps/) were assigned zeros for three pixels that represent the road and right-of-way, whereas a zero was assigned to the single centerline pixel for all others.

We created a 'mosaic' land cover class to recognize areas of natural and semi-natural vegetation with high interspersion but no large patches of any one land cover type. Ninety-meter edges between forest, grassland, and shrubland were collectively defined and modeled as 'mosaic' land cover. Ninety-meter edges were selected after iterative modeling trials were run with wider and narrower edges; wider edges had more and more overlap with large patches of a single land cover type, whereas results using narrower edges did not capture significant mosaics of interspersion of different classes of natural and semi-natural vegetation.

Creation of Landform Coverage

We modeled landforms by calculating neighborhood statistics from original 30-meter DEM input data. Model results were initially classified following Hammond (1954, 1964), who used slope, relief, and profile to define landforms for the United States based on examination of 1:250,000 USGS quadrangles. We modified his definitions in an iterative way using more than 20 modeling trials. For the models, we grouped all pixels into landform classes based on analysis of slope, relief, and profile within circular neighborhoods ranging from 0.25-square kilometers to five-square kilometers. We selected a model in which slope was broken into two categories: more than 50% of the neighborhood on >8% slope or less than 50%, and relief was broken into seven categories; 15 meters or less, 15 to 30 meters, 30 to 90 meters, 90 to 150 meters, 150 to 300 meters, 300 to 900 meters, and greater than 900 meters. Results fit the recognizable landforms of the study area. Hence, 14 landform types are possible (two slope categories multiplied by seven relief categories). We selected a one-kilometer neighborhood size base on visual examination of on-screen overlays of the DEMs with results using smaller and larger neighborhood windows, and overlays of the results from different trials themselves. Smaller neighborhoods did not identify important, larger-resolution landform variations such as gently sloping hills, whereas larger neighborhoods failed to accurately define the spatial location of features such as break-points where plateaus and hills come together on the landscape. Nigh and Schroeder (2002) also selected a one-square kilometer neighborhood roughness grid to delineate ecological subsection lines for Missouri.

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Defining Conservation Opportunity Areas (OAs)

We intersected each land cover distance grid with the road distance grid to identify conservation opportunity areas under a 'liberal' and a 'conservative' model. For the liberal model, we selected all distance grid cell values of three or more for any land cover class and for roads. The result is an OA coverage that represents areas more than 75 meters into the interior of a land cover patch and 75 meters away from any road. For the conservative model, we selected grid cells with a value of six or more for land cover and roads, and the result represents all OAs more than 395.6 meters toward the interior of a land cover patch and away from any road. We selected a liberal and conservation model to define OAs for illustration, and do not suggest that a definitive model applies to all species and habitats, since the impacts of habitat fragmentation and roads are species- and landscape context-specific (see Foreman 2000, Noss and Csuti 1997, Noss et al. 1999, Strittholt and DellaSala 2001, Trombulak and Frissell 2000).

Definition of the Environmental Quality Index

We assigned discrete ordinal ranks from one (low/reduced environmental quality) to five (high/increased environmental quality) to each subsection for anthropogenic vegetation along streams, human use index, cropland on slopes >5%, and the percent of the area of the ecoregion within a conservation opportunity area using the conservative model. These were assigned using ArcView’s ‘natural breaks’ classification method, which assigns natural breaks to continuous data by minimizing the sum of the variance within each class (Jenks 1967). In turn, we summed the ordinal scores for the four metrics by subsection, and then used the 'natural breaks' method to assign all subsections an overall environmental quality index. The metrics we used for this ranking are either identical to, or closely related with, six of the most important nine variables identified by Wickham et al. (1999) in a study of 31 metrics that influence environmental quality in the Mid-Atlantic region. The three factors we did not consider are related to human population and atmospheric deposition of sulfur dioxide. Discrete ordinal ranks from one to five were assigned for each of the four input variables regardless of the variation in the original data, and different results might be expected if we had weighted variables based on their original variation, or for any other reason (Sokal and Rohlf 1995).

RESULTS

Environmental Quality Index Scores

Subsections within the Nebraska Sand Hills, Black Hills, Northwestern Great Plains, and Ozark Highlands ecological sections scored high for overall environmental quality (Figure 2). In contrast, subsections in the central and northeast portions of the study area, including large portions of the North Central Great Plains, Minnesota and Northeast Iowa Morainal Plains, and Central Dissected Till Plains sections had low environmental quality index scores. Only two subsections, the West-central Lakes subsection within the Nebraska Sand Hills in the northwest and the Current River Hills subsection of the Ozark Highlands in the southeast, had the highest scores for all four metrics (Figure 2). Three subsections had the lowest scores for all metrics, including the Deep Loess Hills on the east side of the Missouri River (immediately east of the Nebraska border) in Iowa and Missouri, the Yankton Hills and Valleys on the west side of the Missouri River in Nebraska, and the Loup-Elkhorn Loess and Sand Plains subsection immediately to the west in Nebraska.

Conservation Opportunity Areas (OAs)

Using the liberal model for selection of OAs, a total of 36.5 million hectares, or 30.4% of the study area, was contained within an OA, (Table 1). Using the conservative model, 5.9 million hectares, or 5.0% of the study area, was within an OA. This is a reduction of 84% in the area of OAs when OAs were defined as being more than 75 meters from a road or land cover edge versus more than 395.6 meters. Overall, grassland OAs were more abundant than other OAs, with 18.7% of the region contained within a grassland OA using the liberal model, 4.3% within forest OAs, 7.4% within 'mosaic' land cover OAs, and less than 0.01% within shrubland OAs (Figure 3). The vast north central and east central portions of the region generally had 10% or less of the total area of each ecological section in an OA defined by the liberal model, and less than 2% as defined by the conservative model. In contrast, the Black Hills, Northwestern Great Plains, and Nebraska Sand Hills on the northwest and the Ozark Highlands on the southeast were large subsections with more than 50% of their area in OAs using the liberal model. The Ozark Highlands section contains 3.53 million hectares, or 68%, of all forest OAs under the liberal model, and 0.55 million hectares, or 80%, under the conservative model. The Nebraska Sand Hills and Northwestern Great Plains sections together contain 8.11 million hectares, or 31%, of the grassland OAs under the liberal model, and 3.09 million hectares, or 62%, under the conservative model. The greatest amount of 'mosaic' OAs was in the far northwestern part of the study area (Figure 3). For complete summary statistics of OAs by subsection see Diamond et al. (2001).

Landform Models

Nine of 14 possible modeled landforms, or combinations of two slope categories and seven elevation categories, occurred in the study area. Relatively flat landforms, including flat plains, smooth plains, and irregular plains, make up 84% of the region. Two rougher landform categories, breaks and low hills, make up almost 15% of the region, and the remaining categories, including rugged plains, plains with low hills, plains with hills, and hills account for 1%. Even though some of the landform classes are small overall, they comprise significant portions of individual subsections. The variation revealed by simple landform models is significant because some ecological subdivisions, such as the Ozark Highlands and South Central Great Plains sections, are especially variable in terms of landform and therefore in terms of natural communities, land use, and environmental challenges (see Bailey 1995, Diamond et al. 2001, Noss et al. 1999). The example presented below shows how landforms can be used together with OAs to facilitate conservation planning.

Example: Using OAs for Conservation Planning with Landform

Representation as a Conservation Target

Based on the conservative model for selecting OAs, virtually all of the 77,923 hectares (19% of the subsection) of OAs in the St. Francois Knobs & Basins subsection are forests, with only 48 hectares in grassland OAs and 13 hectares in mosaic land cover OAs. We intersected modeled landforms with these OAs to form OA Groups with similar landforms (Figure 4). We consolidated the original nine landform types into three types, (1) Plains, including flat plains, smooth plains, and irregular plains, (2) Breaks, including breaks, rugged plains, plains with hills and plains with low hills, and (3) Hills, including low hills and hills. If Breaks, Hills, or Plains made up more than 75% of the area of an OA, it was assigned to an OA Group named for that type. If two types made up 75%, then the OA was assigned to a group named for both landforms. Four OA Groups, including Breaks (44%), Hills (24%), Breaks and Hills (28%), and Plains and Breaks (3%) make up 99% of the total.

Rough landforms, including breaks, hills, and low hills, make up 96% of the OAs but only 64% of the St. Francois Knobs & Basins subsection as a whole. Flat OAs, including smooth plains and irregular plains, make up 3% of the OAs and 35% of the subsection. Thus, the OAs under the conservative selection model do not adequately capture flat landforms, whereas rough landforms are over-represented in OAs relative to their abundance in the subsection. In terms of developing conservation plans in an iterative way, we could look at OAs selected under the liberal model in order to capture more flat landforms, or we could accept the results of the conservation model and conclude that no reasonable opportunities to conserve the flat landforms exist in the modern landscape, so restoration projects may be in order. Finally, we illustrated two different models for setting conservation priorities, (1) selection of the largest 10 forest OAs overall within the subsection, and (2) selection of the largest OA, then the second largest, and so on iteratively until at least 10% of the subsection is selected. Under the first scenario 27,404 hectares (6.6% of the subsection) are selected, whereas under the second 41,843 hectares (10.1% of the subsection) are selected (Figure 5). Under both models the selected OA polygons have major landform types that are representative of the landform types within all OAs in the subsection.

DISCUSSION

We used metrics to rank ecoregions for overall environmental quality, defined OAs at finer resolution, and modeled landforms in order to use landform representation as a conservation target and show how OAs can be analyzed together with other data to address planning issues. However, this process of successive refinement does not illustrate the end in terms of conservation planning. The OA data layer can serve as one end point, but should more importantly provide a template for further analyses. Conservation design should incorporate data on different targets, such as rare species, target land cover types, and diversity hotspots, and should include analyses of reserve size requirements and the spatial context of OAs in relation to each other and in relation of existing conserved lands (Hoctor et al. 2000, Kautz and Cox 2000, Noss 1996, Scott et al. 2001a, 2001b).

Conservation opportunity areas (OAs) support natural or semi-natural vegetation and are toward the interior of land cover patches and away from roads. The impacts of different road types, habitat edge versus interior, and habitat fragmentation vary, and no one threshold in terms of distance from a patch edge or from a road is appropriate for all habitats and species (Fahrig 1997, Noss and Csuti 1997, Trombulak and Frissell 2000, Villard et al. 1999). Errors exist in both the NLCD land cover and TIGER roads data from which OAs were modeled. Different road types also represent different levels of threat in terms of future development of human infrastructure. Therefore, the roads and land cover distance grids were developed such that a researcher or planner can discount or emphasize the importance of roads or of habitat edges when defining OAs, depending on the issues of concern.

Ecoregions as Assessment Units

The results of any assessment depend on the area analyzed. An area that appears important within the context of a county might not appear important within a state; an area that appears important within a state might appear less so within a larger region. We considered ecological subsections as a appropriate assessment units, and so included all subsections that intersect the four states that were the primary politically defined units of interest. Ecoregion lines are drawn such that the variation in abiotic factors within is less than that among ecoregions at each level (Bailey

1995). Land use patterns and environmental issues are more uniform within versus among ecoregions, and they therefore provide a logical polygon for conducting environmental assessments and inventories (Omernik and Bailey 1997). Thus, we used ecoregions both as polygons within which to summarize metrics for ranking, and, in the example, as the basis for consideration of landforms as conservation targets.

Landforms As Conservation Targets

Landforms, or 'enduring features,' are appropriate conservation targets because biological diversity is predicted by diversity in abiotic, physical variables (Capen et al. 1999, Kavanagh and Iacobelli 1995, Lapin and Barnes 1995, Nicholls et al. 1998, Noss et al. 1999). Land cover classifications such as the NLCD are not detailed enough to show important variation within a single cover class. In the St. Francois Knobs and Basins example, landforms and therefore the abiotic variables and groupings of ecological land types (enduring features, site types, ecological land units, habitat types) vary within a single NLCD land cover type. Therefore, we grouped together OAs with similar landforms to identify OA Groups, which in turn facilitates direct assessment of the conservation of landforms and, by inference, biotic communities. Our hypothesis is that: (1) NLCD land cover patches vary in terms of biological communities, (2) this variation is predictable and is tied to subtle differences in abiotic conditions, (3) OAs with similar landforms will have similar communities, and these will be different from OAs over different landforms, and, therefore (4) OA Groups are appropriate targets for conserving both landforms and biological communities (see Noss et al. 1999). In the example, modeled OAs represent the best opportunity to conserve forests within the St. Francois Knobs & Basins, and forests vary by landform, so to conserve all of the forest types and all of the landforms within the subsection representatives of all forest OA Groups should be conserved. To test this hypothesis, a list of community types by land cover type and landform should be developed and then field checked via reference to mapped landform/land cover combinations on the ground.

Translating Assessments into Conservation Action

We involved an interagency committee made up of representatives from the United States Environmental Protection Agency, United States Forest Service, United States Fish and Wildlife Service, Natural Resources Conservation Service, Missouri Department of Natural Resources, Missouri Department of Transportation, and Missouri Department of Conservation to help develop the design for this assessment. The partners who helped drive the assessment have different responsibilities and geographic scopes of interest, but all have buy-in to the basic data development and inventory methods. The ease of understanding and flexibility of the basic distance grids, together with buy-in from partners, increases the likelihood that the results will be put to practical use for natural resource planning and management.

For example, EPA's Region 7 in Kansas City has designated the protection of critical ecosystems as one of three regional priorities. The overarching goal of the initiative is to identify, improve, and protect ecosystems that are critical to biodiversity, human quality of life, or landscape function. Implementation of conservation measures on the ground requires a much finer-resolution analysis than is currently available, so that actions can be applied in the kind of site-specific activities that EPA programs conduct. Thus, EPA has supported the development of the OA approach, and plans to build on the results by incorporating additional information on specific conservation targets such as rare and endangered species and aquatic communities. Refined OA analysis results will be used both in building a set of decision support tools for EPA program staff and in targeting ecosystem-specific projects throughout the region.

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LITERATURE CITED

Anderson, M. 2000. Ecological land units in the central Appalachians Ecoregions (CAP). Pp. A6-1-A6-4 *in* Groves, C., L. Valutis, D. Vosick, B. Neely, K. Wheaton, J. Touval, and B. Runnels. Designing a Geography of Hope: A Practioner's Handbook for Ecoregional Conservation Planning, Volume 2, The Nature Conservancy, Arlington, twenty-eight appendices, individually numbered.

Bailey, R. G. 1995. Ecosystem Geography. Springer-Verlag, New York. 204 pp.

Capen, D.E., C. E. Ferree, and E. W. Buford. 1999. Landscape diversity as the basis for a reserve design initiative in Vermont. Gap Analysis Bulletin 8:51-53.

Defenders of Wildlife. 1998. Oregon's Living Landscape: Strategies and Opportunities to Conserve Biodiversity. Defenders of Wildlife. 218 pp.

Diamond, D.D., T.M. Gordon, C.D. True, and R.D. Lea. 2001. An Ecoregion-based Conservation Assessment for EPA Region 7: Iowa, Kansas, Nebraska, and Missouri. US Environmental Protection Agency, Region 7, Kansas City. 37 pp. and ten appendices.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management 61:603-610.

Foreman, R.T.T. 2000. Estimate of the area affected ecologically by the road system of the United States. Conservation Biology 14:31-35.

Frohn, Robert C. 1998. Remote Sensing for Landscape Ecology: New Metric Indicators for Monitoring, Modeling, and Assessment of Ecosystems. CRC Press LLC, Boca Raton, Florida.

Groves, C., L. Valutis, D. Vosick, B. Neely, K. Wheaton, J. Touval, and B. Runnels. 2000. Designing a Geography of Hope: A Practioner's Handbook for Ecoregional Conservation Planning. Volume 1. The Nature Conservancy, Arlington. Ten chapters, individually numbered.

Hammond, E.H. 1954. Small-scale continental landform maps. Annals of the Association of American Geographers 44:33-42.

Hammond, E.H. 1964. Classes and land-surface form in the forty-eight states. U.S.A. Annals of the Association of American Geographers 54: Map supplement 4, scale 1:5 million.

Hoctor, T.S., M.H. Carr, and P.D. Zwick. 2000. Identifying a linked reserve system using a regional landscape approach: the Florida ecological network. Conservation Biology 14:984-1000.

Jenks, G.F. 1967. The data model concept in statistical mapping. International Yearbook of Cartography 7:186-190.

Jennings, M.D. 2000. Gap analysis: concepts, methods, and recent results. Landscape Ecology 15:5-20.

Jones, K. D., K. H. Ritters, J. D. Wickham, R. D. Tankersley Jr., R. V. O'Neill, D. J. Chaloud, E. R. Smith, and A. C. Neale. 1997. An Ecological Assessment of the Unites States Mid-Atlantic Region. EPA/600/R-97/130. US Environmental Protection Agency, Office of Research and Development, Washington, D.C. 104 pp.

Kautz, R.S. and J. A. Cox. 2001. Strategic habitats for biodiversity conservation in Florida. Conservation Biology 15:55-77.

Kavanagh, K. and T. Iacobelli. 1995. Protected areas Gap Analysis methodology. Pp. 10-68 *in* Iacobelli, T., K. Kavanagh, and S. Rowe, Protected Areas Gap Analysis: Planning for the Conservation of Biodiversity, World Wildlife Fund Canada, Toronto. 68 pp.

Lapin, M. and B.V. Barnes. 1995. Using the landscape ecosystem approach to assess species and ecosystem diversity. Conservation Biology 9:1148-1158.

McGarigal, Kevin; Marks, Barbara J. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen.Tech. Rep. PNW-GTR-351. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 122p.

Nicholls, W.F., K.T. Kinningbeck, and P.V. August. 1998. the influences of gemorphological heterogeneity on biodiversity. II. A landscape perspective. Conservation Biology 12:371-379.

Nigh, T.A. and W.A. Schroeder. 2002. Atlas of Missouri Ecoregions. Missouri Department of Conservation Press, Jefferson City. 216 pp.

Noss, R.F. 1996. Protected areas: how much is enough? Pp. 91-119 *in*

R.G. Wright and J. Lemons, eds. Protected Areas: their Role in Environmental Protection. Blackwell Scientific, Inc., Cambridge, Mass. 256 pp.

Noss, R.F. and B. Csuti. 1997. Habitat fragmentation. Pp. 269-304 *in* G.K. Meffe and R.C. Carroll, eds., Principles of Conservation Biology, Sinauer Associated, Inc., Sunderland, Mass. 729 pp.

Noss, R.F, J.R. Strittholt, K. Vance-Boreland, C. Carroll, and P Frost. 1999. A conservation plan for the Kalamath-Siskiyou ecoregion. Natural Areas Journal 19:394-411.

Omernik, J.M., and R.G. Bailey. 1997. Distinguishing between watersheds and ecoregions. Journal of the American Water Resources Association 33:935-949.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). Agricultural Handbook #703. U.S. Department of Agriculture, Washington, D.C.

Riley, J. L., T. Iacobelli, and K. Kavanagh. 1999. Conservation suitability mapping across the Lands for Life planning process in Ontario, Canada. ESRI Arc News, summer 1999: 27.

Ricketts, T.H., E. Dinerstein, D.M. Olson, and C.J. Loucks. 1999. Terrestrial Ecoregions of North America: A Conservation Assessment. Island Press, Washington, D.C. 485 pp.

Scott, J.M, F.W. Davis, R.G. McGhie, R.G. Wright, C. Groves, and J. Estes. 2001a. Nature reserves: do they capture the full range of American's biological diversity? Ecological Applications 11:999-1007.

Scott, J.M., M. Murray, R.G. Wright, B. Csuti, P. Morgan, and R.L. Pressey. 2001b. Representation of natural vegetation in protected areas: capturing the geographic range. Biodiversity and Conservation 10: 1297-1301.

Sokal, R.B. and F.J. Rohlf. 1995. Biometry: The Principals and Practices of Statistics in Biological Research. 3rd Ed. W. H. Freeman and Company, New York. 887 pp.

Strittholt, J.R. and D.A. DellaSala. 2001. Importance of roadless areas in biodiversity conservation in forested ecosystems: case study of the Kalamath-Siskiyou ecoregion of the United States. Conservation Biology 15:1742-1754.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

Villard, M.A., M.K. Trzinski, and G. Merriam. 1999. Fragmentation effects on forest birds: the influence of woodland cover and configuration on landscape occupancy. Conservation Biology 13:774-783.

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, and N. Van Driel. 2001. Completion of the 1990s national land cover data set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering & Remote Sensing 67:650-662.

Wickham, J.D., K.B. Jones, K.H. Riitters, R.V. O'Neill, R.D. Tankersley, E.R. Smith, A.C. Neale, and D.J. Chaloud. 1999. An integrated environmental assessment of the US Mid-Atlantic region. Environmental Management 24:553-560.

Wischmeier, W.H. and D.D. Smith. 1978. Prediction rainfall erosion loss: a guide to conservation planning. Agricultural handbook 537. U.S. Department of Agriculture, Washington, D.C.

FIGURE CAPTIONS

Figure 1. Ecological sections (labeled) and subsections (finer-resolution lines) of Iowa, Kansas, Missouri, and Nebraska (Bailey 1995). All subsections that intersect a state border are included.

Figure 2. Forest, grassland, and mosaic land cover conservation opportunity areas (OAs) using a conservative model, and cropland on slopes >5%, a negative environmental quality indicator.

Figure 3. Environmental quality index scores and individual metric scores by subsection for anthropogenic vegetation along streams, cropland on slopes >5%, a human use index, and the percent of the subsection in conservation opportunity areas using the conservative model (OAs). Discrete ordinal ranks from low quality (1) to high quality (5) were assigned using natural breaks in the original metrics, and the environmental quality index was assigned using natural breaks in the sum values by subsection for the four metrics (Jenks 1977).

Figure 4. Conservation opportunity area (OA) Groups based on landform similarity for the St. Francois Knobs & Basins ecological subsection.

Figure 5. Landforms within all conservation opportunity areas (OAs) versus within two OA subsets, including the largest ten OAs and the largest OAs added iteratively until 10% of the area of the subsection was captured.

TABLE TITLES

Table 1. Conservation opportunity areas (OAs) by land cover type based on a liberal and conservative model. The liberal model selected all land cover patches that are at least 75 meters from a road and toward the interior of a land cover patch, whereas the conservative model used a 395.6-meter threshold.

Figure 1. Ecological sections (labeled) and subsections (finer-resolution lines) of Iowa, Kansas, Missouri, and Nebraska (Bailey 1995). All subsections that intersect a state border are included.

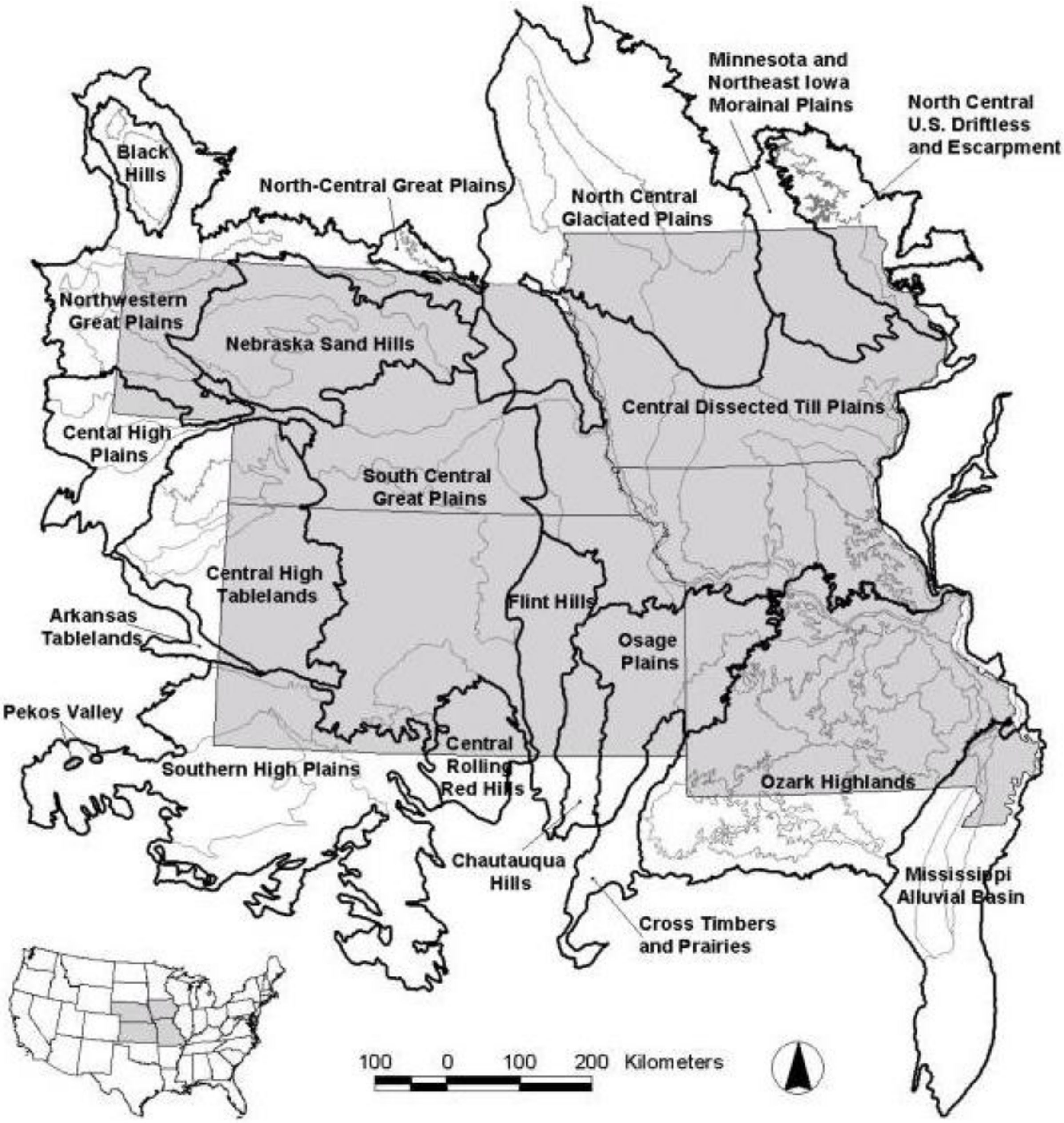

Figure 2. Forest, grassland, and mosaic land cover conservation opportunity areas (OAs) using a conservative model, and cropland on slopes >5%, a negative environmental quality indicator.

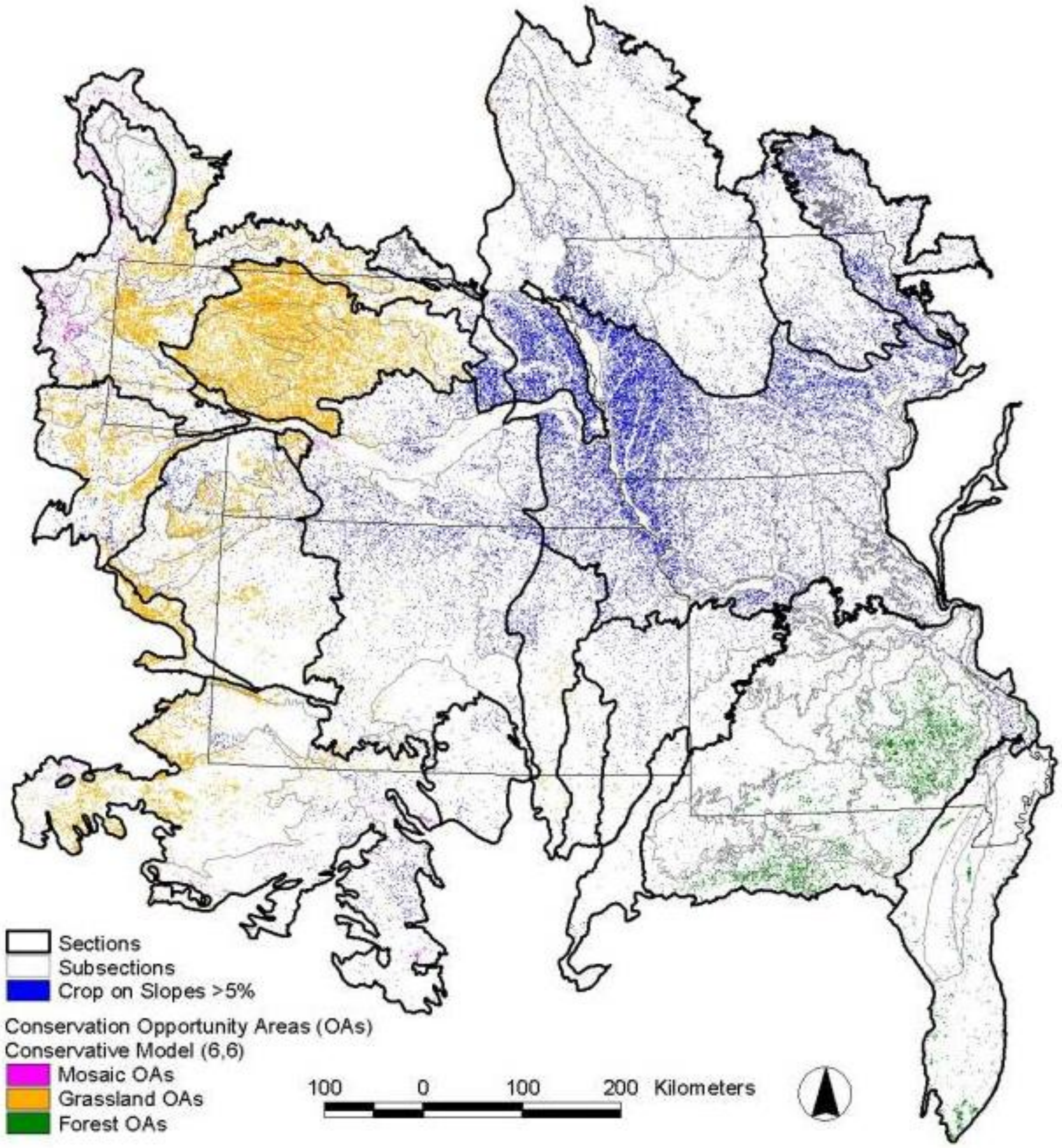

Figure 3. Environmental quality index scores and individual metric scores by subsection for anthropogenic vegetation along streams, cropland on slopes >5%, a human use index, and the percent of the subsection in conservation opportunity areas using the conservative model (OAs). Discrete ordinal ranks from low quality (1) to high quality (5) were assigned using natural breaks in the original metrics, and the environmental quality index was assigned using natural breaks in the sum values by subsection for the four metrics (Jenks 1977).

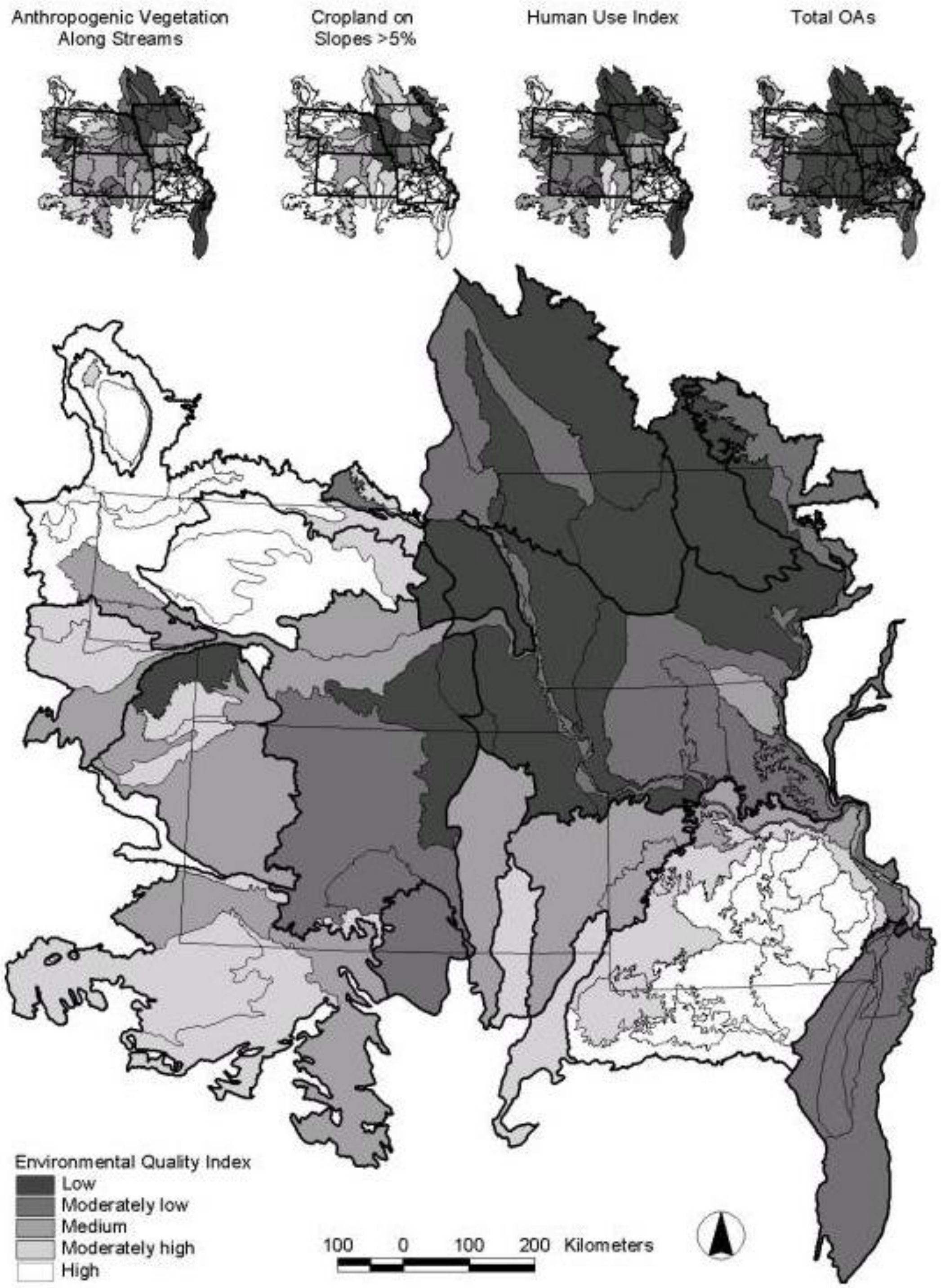

Figure 4. Conservation opportunity area (OA) Groups based on landform similarity for the St. Francois Knobs & Basins ecological subsection.

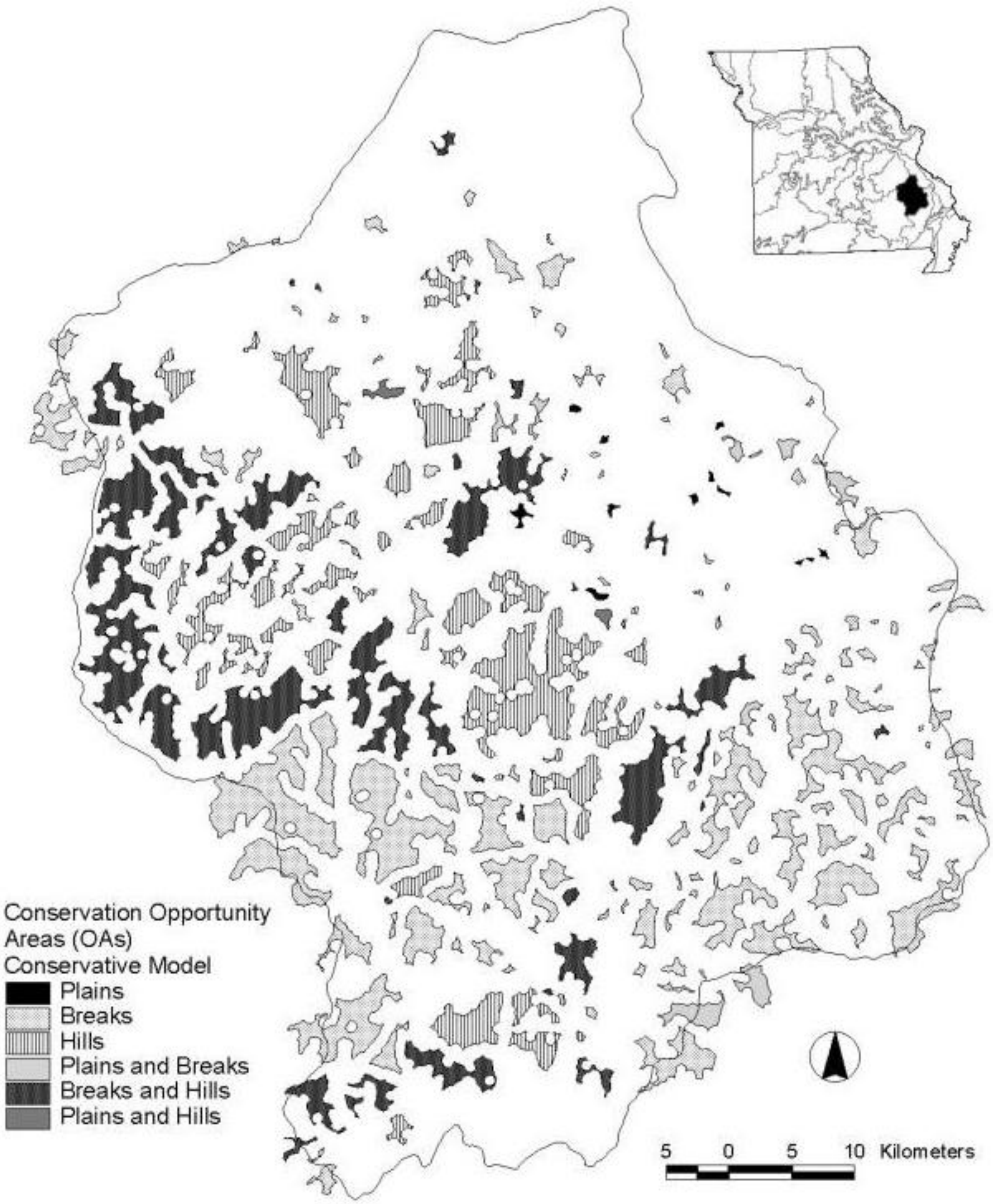

Figure 5. Landforms within all conservation opportunity areas (OAs) versus within two OA subsets, including the largest ten OAs and the largest OAs added iteratively until 10% of the area of the subsection was captured.

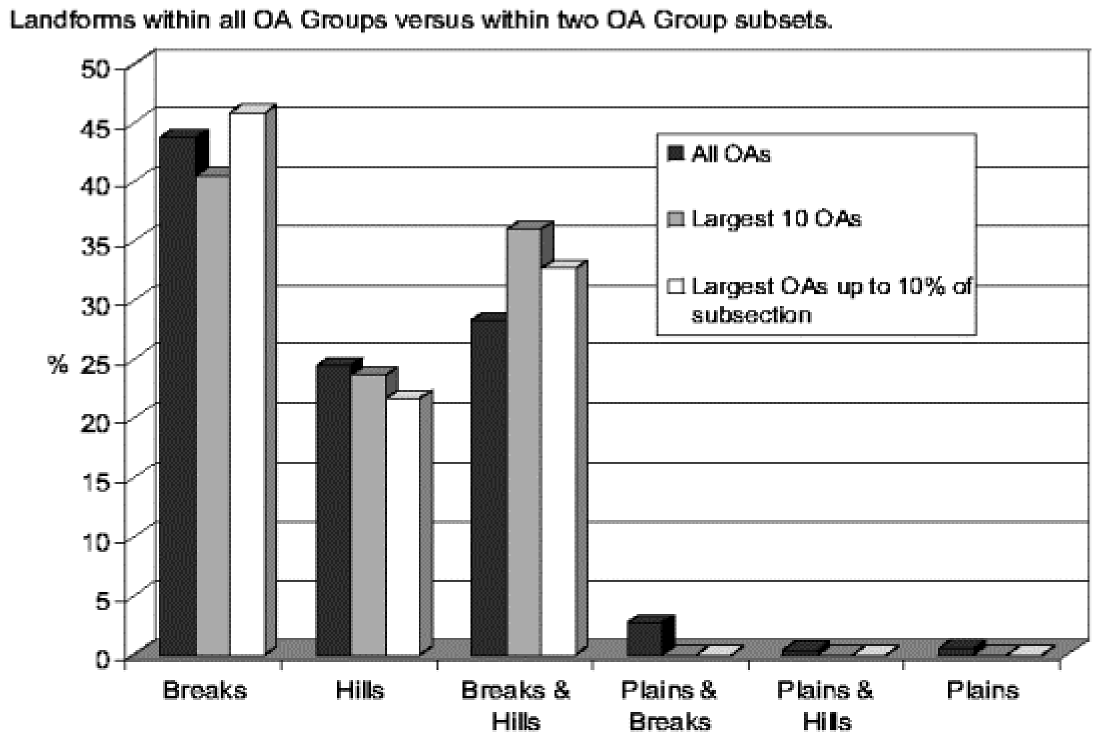

Table 1. Conservation opportunity areas (OAs) by land cover type based on a liberal and conservative model. The liberal model selected all land cover patches that are at least 75 m from a road and toward the interior of a land cover patch, whereas the conservative model used a 395.6-m threshold.

Section	Area	Forest 3,3		Forest 6,6		Grass 3,3		Grass 6,6		Mosaic 3,3		Mosaic 6,6		Total OAs 3,3		Total OAs 6,6	
	ha	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Ozark Highlands	12,299,928.39	3,533,111	28.7	554,483	4.5	868,711	7.1	437	0.0	2,298,732	18.7	1,443	0.0	6,701,131	54.5	556,362	4.5
North Central U.S. Driftless and Escarpment	3,094,043.83	291,064	9.4	1,249	0.0	61,114	2.0	0	0.0	328,631	10.6	35	0.0	680,809	22.0	1,285	0.0
Minnesota and Northeast Iowa Morainal Plains	2,868,118.19	14,922	0.5	65	0.0	23,184	0.8	0	0.0	19,818	0.7	0	0.0	57,924	2.0	65	0.0
Chautauqua Hills	1,213,094.78	58,335	4.8	282	0.0	322,197	26.6	7,563	0.6	265,539	21.9	1,078	0.1	646,070	53.3	8,923	0.7
Mississippi Alluvial Basin	5,817,688.44	513,174	8.8	107,888	1.9	23,960	0.4	141	0.0	27,937	0.5	0	0.0	565,071	9.7	108,029	1.9
North Central Glaciated Plains	14,411,492.60	18,977	0.1	45	0.0	551,664	3.8	9,493	0.1	103,646	0.7	706	0.0	674,287	4.7	10,244	0.1
Central Dissected Till Plains	17,996,810.39	243,899	1.4	854	0.0	537,791	3.0	1,935	0.0	796,657	4.4	1,011	0.0	1,578,346	8.8	3,799	0.0
Osage Plains	4,370,694.27	82,967	1.9	756	0.0	603,575	13.8	6,566	0.2	273,509	6.3	93	0.0	960,052	22.0	7,414	0.2
Flint Hills	2,627,806.14	5,040	0.2	11	0.0	656,329	25.0	21,392	0.8	270,358	10.3	1,109	0.0	931,727	35.5	22,512	0.9
Cross Timbers and Prairies	1,500,957.67	80,168	5.3	2,003	0.1	269,987	18.0	1,526	0.1	271,301	18.1	123	0.0	621,456	41.4	3,651	0.2
Pekos Valley	38,766.24	4,083	10.5	157	0.4	10,740	27.7	1,408	3.6	15,290	39.4	763	2.0	30,477	78.6	2,328	6.0
Central Rolling Red Hills	1,852,168.62	249	0.0	0	0.0	150,630	8.1	3,384	0.2	39,577	2.1	131	0.0	190,456	10.3	3,514	0.2
Southern High Plains	11,933,785.46	17,435	0.1	29	0.0	3,383,507	28.4	614,845	5.2	1,789,064	15.0	74,270	0.6	5,255,504	44.0	689,612	5.8
Central High Tablelands	7,013,850.95	0	0.0	0	0.0	2,164,012	30.9	494,394	7.0	38,358	0.5	1,202	0.0	2,202,407	31.4	495,596	7.1
Northwestern Great Plains	8,007,108.32	20,011	0.2	0	0.0	3,517,869	43.9	950,756	11.9	1,342,615	16.8	144,080	1.8	4,896,151	61.1	1,095,058	13.7
Cental High Plains	3,242,603.42	0	0.0	0	0.0	1,431,081	44.1	407,260	12.6	28,664	0.9	389	0.0	1,460,190	45.0	407,649	12.6
Arkansas Tablelands	690,222.42	33	0.0	0	0.0	406,780	58.9	171,326	24.8	7,273	1.1	0	0.0	414,086	60.0	171,326	24.8
Nebraska Sand Hills	5,745,020.23	744	0.0	0	0.0	4,589,604	79.9	2,134,854	37.2	41,704	0.7	695	0.0	4,632,052	80.6	2,135,549	37.2
North-Central Great Plains	509,511.76	3,634	0.7	16	0.0	97,151	19.1	2,662	0.5	81,549	16.0	1,971	0.4	182,334	35.8	4,649	0.9
South Central Great Plains	13,407,628.66	3,850	0.0	0	0.0	2,500,502	18.6	160,704	1.2	372,141	2.8	10,955	0.1	2,876,538	21.5	171,658	1.3
Black Hills	1,288,877.89	295,090	22.9	19,768	1.5	199,575	15.5	9,800	0.8	437,085	33.9	14,341	1.1	931,767	72.3	43,909	3.4
TOTAL	119,930,178.66	5,186,787	4.3	687,605	0.6	22,369,961	18.7	5,000,444	4.2	8,849,446	7.4	254,393	0.2	36,488,834	30.4	5,943,132	5.0